

# Crystalline Cores of Neutron Stars\*

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First order phase transitions have been much studied in nuclear physics and cosmology. A remarkable aspect of the coexistence phase in substances having more than one independent component (or conserved charge) has been overlooked until recently [1]. If the substance is allowed to reach equilibrium and one of the conserved charges is the electric charge, then the rarer phase in the coexistence regime will form a crystalline lattice immersed in the dominant phase. The form and spacing of the rare phase objects will vary as its proportion of the mixed phase varies. This is true in general.

In particular, the quark phase transition has been discussed for many years. In the original and succeeding discussions between 1976 and 1990, the transition was treated in analogy to the liquid-vapor transition in water—a single-component substance. However neutron stars are characterized by two independent conserved charges, the baryon and electric charges. A first order phase transition in multi-component substances is profoundly different from that in a single-component one. There are four main aspects that impinge on the structure of neutron stars: (1) The two phases in coexistence adjust their internal structure at each proportion of the phases so as to minimize the total energy—a degree of freedom unavailable to a single-component substance. (2) One consequence of the readjustment—actually a rearrangement in the concentrations of the conserved charges—is that the pressure varies as a function of the proportion. For this reason the coexistence region of the two phases can extend over a non-zero radial range in the monotonically varying pressure environment of a star (unlike the coexistence of the two phases of a single-component substance for which the pressure is constant, causing the mixed phase to be squeezed out by the gravitational field of a star). (3) The readjustment

of the two phases in each others presence lowers the value of the critical pressure (and density). (4) The degree of freedom afforded by the possibility of reapportioning the conserved charges is exploited by the isospin symmetry energy of nuclear matter with the twin consequence that (a) the charge densities of the two equilibrium phases are unequal and non-zero so that neutrality is achieved not by vanishing charge density but by cancelling charges (neutrality of stars is a global, not a local constraint on their constitution); (b) the spatial arrangement of the two phases in equilibrium that minimizes the Coulomb and surface energies is a crystal lattice (of typically nuclear dimensions).

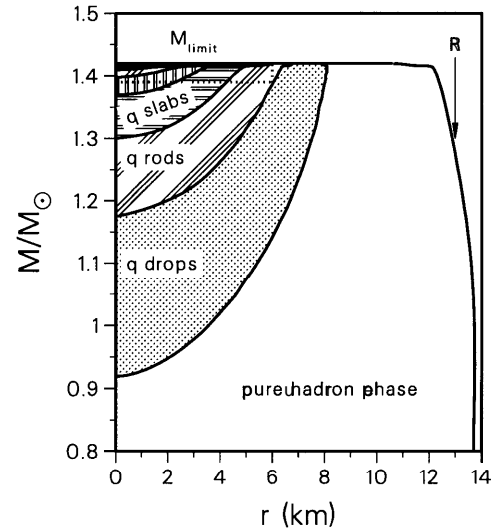


Figure 1: Radial boundaries of the various phases, pure quark, mixed (and the geometrical phases, for which 'q drops' means quark drops immersed in nuclear matter) and pure hadronic fluid for stars of various masses and stellar radius  $R$  for stars.

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[1] N. K. Glendenning, Phys. Rev. D, **46** (1992) 1274.